

Article

Leaching of Organic Toxic Compounds from PVC Water Pipes in Medina Al-Munawarah, Kingdom of Saudi Arabia

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Abstract: It is well established that the use of synthetic material in water pipes significantly affects the quality of domestic water, especially trace organics that are leached through with the flow of water. In the present study, the migration of volatile organic compounds (VOCs) from water pipes manufactured of polyvinyl chloride (PVC) has been investigated using static laboratory conditions and in residential areas. The contact of deionized water with various PVC pipes for three successive test periods of 24, 48, and 72 h duration has been made. Twenty water samples were collected from houses within Medina Al-Munawarah residential area and were analyzed by using solid phase extraction, followed by high resolution gas chromatography with flame ionized detector (GC-FID). The presence of carbon tetrachloride (CTC), toluene, chloroform, styrene, o-xylene, bromoform (BF), dibromomethane (DBM), cis-1,3-dichloropropane (Cis-1,3-DCP), and trans-1,3-dichloropropane (Trans-1,3-DCP) was initially confirmed. The most frequent contaminants found were DBM, CTC, and toluene that were monitored in 55%, 50%, and 45% of samples, respectively. The levels of CTC, Cis-1,3-DCP, and Trans-1,3-DCP were found to exceed the World Health Organization (WHO) limits in 50%, 20%, and 20% of samples, respectively. The migration test indicated that nine of the targeted contaminants occur in a double distilled water sample incubated in pipe in laboratory level experiment. This implies that these components are more likely to migrate from PVC pipe in home plumbing systems network.

Keywords: volatile compounds; drinking water; solid phase extraction (SPE); polyvinylchloride (PVC)

1. Introduction

Contamination of drinking water by chemicals can occur at several stages of its journey from source to tap, and to user [1,2]. The plastic materials in water distribution system and household have a great impact on water when in contact with chemical substances. In water distribution system, the most commonly used plastic pipes are polyvinylchloride (PVC), cross-linked polyethylene (PEX), and polyethylene (PE) pipes that can leach organic chemicals with harmful health effects and cause water quality to deteriorate [3,4]. These include oxygenated-compounds ethyl-tertbutyl ether (ETBE), methy-tertbutyl ether (MTBE), and their degradation product tertbutylalcohol (TBA), as well as degradation products of antioxidants, such as 2,4-ditertbutyl phenol (DTBP) and BTEX (benzene,

toluene, ethylbenzene, and xylene) [5–8]. A previous study showed that ethyl-tertbutyl ether (ETBE), methy-tertbutyl ether (MTBE), and TBA leached from plastic pipes affects the quality of water [9].

Whelton et al. [10] revealed that 158 contaminants are known to leach from cross-linked polyethylene (PEX) pipes into drinking water. Many other contaminants still remain unknown, and also mixture effect of the chemicals is not well understood. Thus it is suggested that the effects-directed cell-based assays can be a good solution [11,12]. Compounds detected in water pipes can be originated from the household pipe [13,14]. Previous studies on 35 organic contaminants in European water found that the concentrations of the contaminants were up to 4 µg/L [13,15,16]. Pollution of surface water is one of the key environmental harms that can pose significant toxicological concern, although at low concentration [17,18]. Consequently, it is necessary to identify sources and quantities in the drinking water. Identification and monitoring of these contaminants is of critical importance in an attempt to keep the quality of drinking water safe for the health of human beings, and in the interpretation of complex datasets to evaluate water quality. A monitoring program for organic chemicals in water often results in datasets with a large number of parameters, which is often difficult to understand [19,20].

At the city of Medina Al-Munawarah, PVC pipes have been exhaustively used in civil construction of water supply for the last several years. The present study aims to examine the levels of trace volatile hydrocarbons (including halogenated) that are frequently released from PVC pipes used in buildings and houses. The study was done under different stagnation periods to assess the level of these compounds.

2. Materials and Methods

2.1. Chemicals Apparatus and Plastic Pipes

Volatile mega mix standard (30497) for 26 volatile organic compounds was purchased from Restek Company (Bellefonte, Production Assistance (PA), United State of America (USA)). Sodium sulphate, hydrochloric acid, dichloromethane (DCM), methanol, and acetone (Hi-purity) were purchased from Sigma, Aldrich Street. Louis, Missouri (MO), 63178 United State of America (USA) etc. Deionized water was obtained from Milli-Q ultra-pure water system (Merck Millipore) having conductivity <0.061 micro Siemens (µs).

2.2. Preparation of Standard Solution

A three-point calibration linear graph generated using three different concentrations of working standard solutions, using DCM from the stock standard solutions of volatile organic compounds, was applied for calibration and quantification of gas chromatography with flame ionized detector. Figure 1 illustrates the flowchart of the experiment.

2.3. Samples Preparation and Solid Phase Extraction (SPE)

A solid phase extraction (SPE) manifold from Auto Science (Panamera's China) operated with vacuum pump (Busch Company, Virginia (VA), United State of America (USA)) was used in this study. Hydrophilic-lipophilic-balanced 6 mL/200 mg column from Star Lab Scientific (Xian City Shaanxi Province, China) was used for SPE. Methylene chloride was used as solvent for elution of adsorbed organics [1,21]. The eluted extract was passed through sodium sulfate to remove water, and was concentrated as needed. The cartridge was rinsed twice with 2.5 mL aliquots of methylene chloride, then was cleaned twice with 2.5 mL of aliquots of methanol in such a way that methanol will not go below the top of the cartridge packing. The cartridge was then rinsed twice with 0.05 M HCl for equilibration. After that, loading of 100 mL sample of pH 2 to the column was done at a rate of 5 mL/min, with a vacuum pressure of 20 psi, dried with oxygen free N₂ gas, then attentive volatiles components were eluted with 1 mL of methylene chloride with oven pure Na₂SO₄. In a similar way,

another 100 mL water sample, which was pre-adjusted to pH 12, was weighed down to one more cartridge following a similar process.

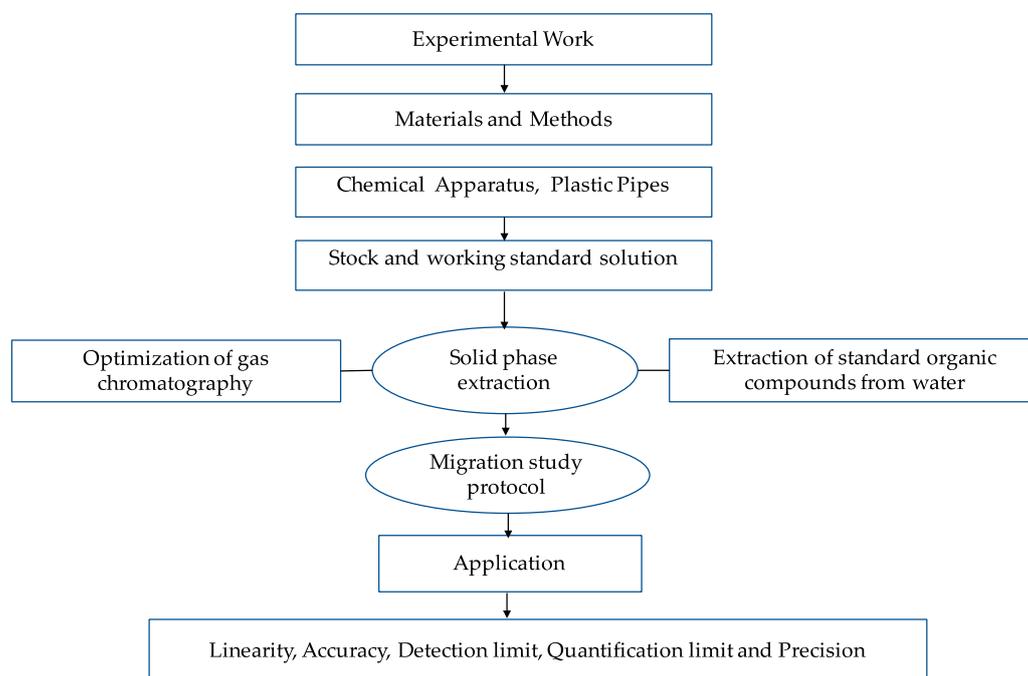


Figure 1. Flowchart of the experiment.

2.4. Optimization of Gas Chromatographic

Gas chromatography with flame ionized detector (GC-FID) detector pattern 1300, Mtx-5 analytical column Mxt-5 (Rt × 30 m × 0.25 mm × 0.25 μm thickness), and integrator, thermo model 1300, (Thermo Fisher Scientific, United State of America (USA)) were used in the analysis. Hydrogen gas was used as the carrier gas at a constant flow of 5 mL.min⁻¹. A total of 2 μL of extract solution that was injected in the split-mode to introduction port at an initial temperature of 280 °C and oven temperature was set at 45 °C for 2 min, raised by 5 °C per min to 280 °C and then held at 280 °C for 10 min were used for the analysis of the targeted VOCs compounds extracted from water [21].

2.5. Extraction of Volatile Organic Compounds from Synthetic Water Samples

Synthetic water containing nine volatile organic compounds was prepared at level of 20 μg/L. Water sample was then subjected to solid phase extraction and elution as described above, and the mixture was analyzed by GC-FID. Table 1 shows the results for recovery tests of synthetic mixtures of organic compounds from water sample.

Table 1. Compounds, amount added, amount found, and % of recovery tests of synthetic mixtures of organic compounds from water sample.

Compound	Amount Added (μg/L)	Amount Found (μg/L)	Recovery (%)
1. Carbon tetrachloride	20	19.80	99
2. Chloroform	20	19.45	97.25
3. Toluene	20	19.12	95.60
4. Styrene	20	19.34	96.70
5. Bromoform	20	19.57	97.85
6. Dibromomethane	20	19.85	95.25
7. Cis-1,3-dichloropropane	20	19.22	96.15
8. Trans-1,3-dichloropropane	20	18.42	92.10
9. O-xylene	20	19.70	98.50

The GC-FID system was used for the analysis of standard mixture of organic compounds extracted from water using different temperature programs. A reasonable separation for individuals VOCs was obtained as shown in chromatograms in Figures 2 and 3.

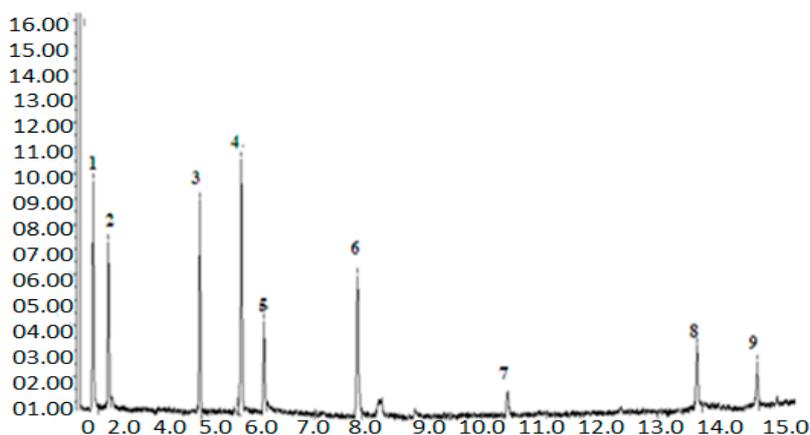


Figure 2. Chromatogram of VOCs detected from recovery test. 1-carbontetrachloride, 2-chloroform, toluene, 4-styrene, 5-bromoform, 6-dibromomethane, 7-is-1,3-dichloropropane, 8-trans-1,3-dichloropropane, and 9-O-xylene.

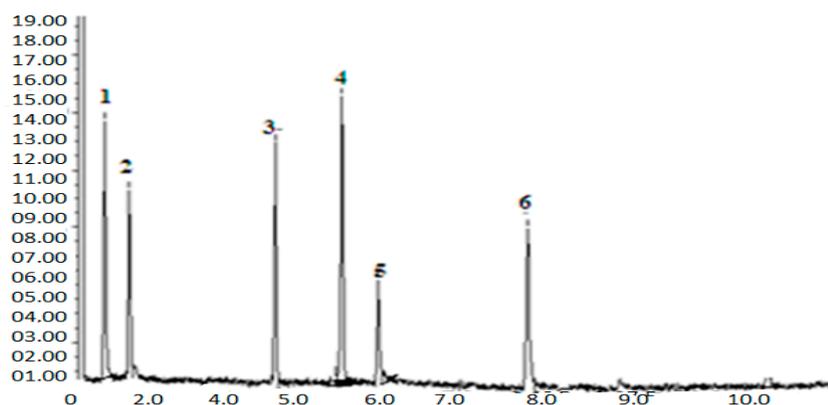


Figure 3. Chromatogram of analysis of water samples collected from residential area. 1-carbontetrachloride, 2-chloroform, 3-toluene, 4-styrene, 5-bromoform, and 6-dibromomethane.

2.6. Migration Study Protocol

Three 2 m length pieces of PVC pipes (inner diameter of 32 mm) were used to accumulate the necessary sample quantity for investigation. The pipe was flushed thrice-period through double distilled water, and filled with water and left for stagnation of 24, 48, and 72 h. The stagnated water samples were then extracted using the same procedure as above.

2.7. Applications

After optimization, the above method was applied to analyze water samples collected from the city water supply. Tap water samples from the residential area were collected in brown bottles (1 L) in the morning after 8 h incubation. Then, water was flushed for three minutes, bottles were washed and refilled with same water and kept in an icebox till the transportation to the lab. Water samples were taken from houses constructed with polymeric materials. However, it is difficult to obtain information of the pipe network due to the fixing of these pipes inside the building walls. For migration experimental study, the pipe was new and unused, and the date of manufacturing was between 3 to 5 years old. Water samples were delivered to the laboratory in boxes containing ice to avoid any contamination to the samples' conditions. The sample spot was calculated to cover up

an extensive choice of key site, which reasonably represents the determinate source of water quality in Medina Al-Munawarah. Table 2 shows the total 20 water samples that were collected from four different locations in Medina Al-Munawarah city.

Table 2. Sample IDs, home year, pipe types, sampling area, and time of samples collection from Medina Al-Munawarah city.

Sample ID	Home Year	Pipe Type	Sampling Area	Time of Collection
M1 to M5	2006–2008	PVC	Al Quoba Street	7 a.m. to 9 a.m.
M6 to M10	2008–2011	PEX	JableOuhad Street	11 a.m. to 1 p.m.
M11 to M15	2011–2014	PE	Al Azizia Street	2 p.m. to 4 p.m.
M16 to M20	2014–2017	PVC	Abdullah Street	7 p.m. to 9 p.m.

2.8. Linearity, Accuracy Detection Limit, Quantification Limit, and Precision

Excellent linearity with 0.9930 for all investigated VOCs was found for the method suitability test. Accuracy was also assessed by improvement test as depicted in Table 3. The recoveries were found from 92% to 97%. The detection and quantification limits of VOCs, as well as all confirmation results, were presented in Table 3. Accuracy of the technique was expressed as the qualified standard deviations (RDS) obtained, starting from the determination of three SPE in deionized water. A representative group of deionized water shows principles were less than 5.5% for all preferred compounds. These consequences validate the efficiency of SPE technique for the determination of organic compounds migrating from plastic pipes into drinking water.

Table 3. Compounds, average concentration, % RSD, SPK $\mu\text{g/L}$, % Recovery and MDL $\mu\text{g/L}$.

Compounds	Average Concentration ($\mu\text{g/L}$)	RSD (%)	SPK $\mu\text{g/L}$	Recovery (%)	MDL $\mu\text{g/L}$
Carbon tetrachloride	0.639	3.1	0.5	128	0.07
Chloroform	0.607	10.3	0.5	121	0.21
Toluene	0.628	5.6	0.5	126	0.12
Styrene	0.559	5.5	0.5	112	0.10
Bromoform	0.596	4.9	0.5	119	0.10
Dibromomethane	0.646	6.0	0.5	129	0.13
cis-1,3-DCP	0.564	6.7	0.5	113	0.13
trans-1,3-DCP	0.508	5.7	0.5	102	0.10
O-xylene	0.569	6.2	0.5	114	0.12

3. Results and Discussion

3.1. Volatile Organic Contamination Detected in Tap Water Samples

In the present study, nine VOCs contaminants were identified and quantified in 20 drinking water samples collected from houses of different ages in Medina Al-Munawarah city, Kingdom of Saudi Arabia. The results disclosed that the VOCs such as carbon-tetrachloride, chloroform, toluene, styrene, xylene, bromoform, DBM, Cis-1,3-DCP, and Trans-1,3-DCP exist in the analyzed samples at inconstant levels. All the results are summarized in Tables 4–6 with the summary of statistical data. The numerical data obtained from the volatile organic compounds analysis characterization in this study were evaluated by descriptive statistical analysis (minimum, maximum, mean, range and standard deviation) and samples were compared with the standard limits of the World Health Organization. The occurrence of volatile organic compounds in water from various sources has been evaluated by previous studies [22–24]. Various chlorinated solvents, by-products, and unlike levels of oxygenated (ETBE) also have been detected in water samples from accommodation homes network.

Table 4. Minimum and maximum concentrations, SD± and allowable limits of the World Health Organization (WHO).

Location	Xylene	CTC	Chloroform	Toluene	Styrene	BF	DBM	Cis-1,3-TCP	Trans-1,3-TCP
M-01	* 0.09 (±0.37)	** 19.73 (±0.37)	** 16.42 (±0.16)	4.33 (±0.12)	* 0.03 (±0.01)	0.05 (±0.01)	0.21 (±0.01)	nd	0.45 (±0.02)
M-02	nd	nd	nd	0.05 (±0.01)	nd	nd	0.09 (±0.02)	nd	nd
M-03	nd	12.05 (±0.08)	nd	0.64 (±0.02)	nd	0.06 (±0.01)	0.16 (±0.02)	nd	1.18 (±0.05)
M-04	nd	nd	nd	nd	nd	nd	nd	0.58 (±0.04)	nd
M-05	nd	nd	nd	nd	nd	* 0.03 (±0.01)	nd	nd	nd
M-06	nd	nd	nd	* 0.02 (±0.01)	nd	nd	* 0.06 (±0.01)	nd	0.61 (±0.05)
M-07	nd	nd	nd	nd	nd	nd	nd	nd	* 0.41 (±0.01)
M-08	0.34 (±0.02)	16.03 (±0.17)	nd	** 9.52 (±0.11)	2.06 (±0.03)	nd	0.25 (±0.02)	** 0.84 (±0.04)	1.52 (±0.01)
M-09	5.63 (±0.06)	6.42 (±0.10)	9.52 (±0.11)	1.31 (±0.01)	3.01 (±0.03)	nd	0.39 (±0.01)	* 0.56 (±0.02)	2.23 (±0.03)
M-10	nd	9.36 (±0.08)	11.10 (±0.12)	1.71 (±0.01)	2.02 (±0.02)	nd	0.41 (±0.02)	0.58 (±0.02)	** 2.50 (±0.03)
M-11	nd	10.93 (±0.11)	nd	nd	nd	nd	0.02 (±0.01)	nd	nd
M-12	7.21 (±0.09)	8.21 (±0.07)	nd	0.58 (±0.01)	nd	** 0.71 (±0.07)	0.13 (±0.01)	nd	nd
M-13	nd	* 6.24 (±0.09)	0.10 (±0.01)	nd	nd	nd	nd	nd	nd
M-14	nd	15.19 (±0.18)	* 0.06 (±0.01)	nd	nd	0.15 (±0.01)	** 1.71 (±0.01)	nd	nd
M-15	** 8.31 (±0.10)	6.24 (±0.10)	nd	nd	2.56 (±0.02)	0.06 (±0.01)	0.28 (±0.01)	nd	nd
M-16	nd	Nd	nd	nd	nd	nd	nd	nd	nd
M-17	nd	Nd	nd	nd	nd	nd	nd	nd	nd
M-18	5.32 (±0.06)	nd	nd	3.12 (±0.03)	** 4.21 (±0.04)	nd	nd	nd	nd
M-19	Nd	nd	nd	nd	nd	nd	nd	nd	nd
M-20	7.17 (±0.09)	nd	nd	nd	4.20 (±0.03)	nd	nd	nd	nd
WHO Limit	1750	0.50	80	150	100	80	80	0.50	0.50

Values are presented in average (n = 3), nd: not detected, *: minimum and **: maximum concentration and standard deviations are given in parenthesis.

Table 5. Incubation time, total concentration (µg/L), and WHO limits of leached VOCs compounds from Polyvinyl chloride (PVC) pipes.

Analytes	24 h	48 h	72 h	WHO Limit
Carbon tetrachloride	4.84 ± 0.35	11.93 ± 0.71	3.95 ± 0.21	0.5
Chloroform	8.19 ± 0.42	9.6 ± 0.61	6.93 ± 0.41	80 EPA
Toluene	1.79 ± 0.21	1.86 ± 0.04	1.93 ± 0.04	150
Styrene	0.03 ± 0.01	0.02 ± 0.01	0.011 ± 0.01	100
Bromoform	0.14 ± 0.05	0.16 ± 0.02	0.19 ± 0.02	80 EPA
Dibromomethane	0.07 ± 0.02	0.14 ± 0.02	0.36 ± 0.03	80 EPA
Cis-dichloropropane	0.57 ± 0.08	0.71 ± 0.03	0.70 ± 0.02	0.5 California
Trans-dichloropropane	0.42 ± 0.05	0.63 ± 0.03	1.15 ± 0.05	0.5 California
O-xylene	0.12 ± 0.03	0.18 ± 0.01	0.68 ± 0.03	1750

Table 6. Concentration ($\mu\text{g/L}$) range, mean, and standard deviation of VOCs leached from PVC pipes.

Analytes	Range	Mean	$\pm\text{SD}$
Carbon tetrachloride	4.14–12.64	7.33	4.63
Chloroform	7.34–10.21	8.72	1.44
Toluene	1.07–2.000	1.66	0.51
Styrene	0.02–0.040	0.03	0.01
Bromoform	0.18–0.210	0.19	0.02
Dibromomethane	0.09–0.390	0.21	0.16
Cis-dichloropropane	0.65–0.74	0.70	0.47
Tans-dichloropropane	0.47–1.20	0.78	0.38
O-xylene	0.15–0.71	0.35	0.31

Xylene was identified in 35% of water samples and ranged from 0.09 to 8.39 $\mu\text{g/L}$ with mean value of 1.70 $\mu\text{g/L}$. This fragment was conformed in samples collected from houses of different ages. The xylene concentrations in samples were within the permissible limit confirmed by EPA (1750 $\mu\text{g/L}$). Xylene mixtures are used to make phthalate, polyester, fiber plasticizers, and layer fabrication.

The minimum and maximum concentration values for CTC in drinking water samples were 6.24 and 19.73 $\mu\text{g/L}$, respectively. This contaminant was monitored in 50% of water samples, with 50% exceeding the maximum contamination level (MCL) 0.5 $\mu\text{g/L}$ set by EPA. This compound is commonly used in manufacturing of plastic. A previous study conducted in the USA showed CTC in 30 drinking-water samples from a total 945 samples from various cities, found at signify level at maximum concentration of 16 $\mu\text{g/L}$ [25].

Chloroform was detected in 25% of samples with concentration ranged from 0.06–16.42 $\mu\text{g/L}$, with mean value of 1.90 $\mu\text{g/L}$. However, the level was in the permissible limit confirmed by WHO (80 $\mu\text{g/L}$). Chloroform is a chemical used to make other chemicals and a byproduct of chlorinating water. According to Minnesota public drinking water, 29% of drinking water recorded from 1993 to 2016 showed the presence of chloroform with some of the samples exceeding the Minnesota Department of Health (MDH) of 20 ppb. The medium level of chloroform detected in public drinking water was at 1.5 ppb [23].

Toluene, another volatile contaminant recorded in 45% of samples varies in concentration from 0.02 to 9.52 $\mu\text{g/L}$ with a mean value of 1.06 $\mu\text{g/L}$. Toluene is used as a solvent, particularly for coatings, and in the production of polymers. It also occurs as by-product of styrene manufacturer [26]. Approximately 1% of public drinking-water systems in the USA contain toluene level that is above 0.5 $\mu\text{g/L}$, whereas in Canada, samples from 30 drinking-water contained an average of 2 $\mu\text{g/L}$ of toluene [27]. In an Ontario drinking-water supply, the study shows that concentrations of toluene were up to 0.5 $\mu\text{g/L}$ [28]. The concentration levels of toluene in water samples were under the permissible limit stated by WHO (150 $\mu\text{g/L}$).

The minimum and maximum concentrations of styrene recorded in water samples vary from 0.03 to 4.21 $\mu\text{g/L}$. This contaminant was detected in 35% of water samples collected from Medina Al-Munawarah city. The guideline value of this contaminant stated by EPA is 100 $\mu\text{g/L}$. Styrene is originated from finished drinking-water in the USA and in commercial, charcoal-filtered drinking-water in New Orleans at concentrations of less than 1 $\mu\text{g/L}$.

The bromoform contaminant identified in drinking water samples was found in 30% of samples and varies in concentration between 0.03 and 0.71 $\mu\text{g/L}$. Based on the data established from eight Canadian provinces, mean concentrations of bromoform (CHBr_3) were usually less than the exposure limit, or just about 0.5 $\mu\text{g/L}$, and the entity values were less than 10 $\mu\text{g/L}$. On the other hand, average and maximum bromoform levels exceeded 30 $\mu\text{g/L}$ over this stage.

DBM contaminant noticeable rates and concentration values of 55% of water samples collected are shown in Table 4. The total concentrations were ranged from 0.02 to 1.71 $\mu\text{g/L}$, with a mean value of 0.186 $\mu\text{g/L}$. DBM in drinking-water supplies has been identified, and samples were collected in the

USA with the concentration ranged from 0.01 to 15 µg/L. In Australia, a maximum concentration of 94 µg/L (DBM) was measured in 15 samples.

Cis-1,3-DCP and Trans-1,3-DCP dominated in 20 drinking water samples in 20% and 35%, each with total concentration ranging from 0.56 to 0.84 µg/L, and 0.41 to 2.5 µg/L, respectively. These two contaminants were found in the USA from 41 out of 1088 water samples and in 10 out of 3949 water samples collected from various sources. Concentration levels of these contaminants in water were found from 1.3 µg/L to 3.4 µg/L. Inhalation of 1,3-dichloropropane at concentration above 6.8 g/m³ was creating problems of gasping, coughing, pain of sub sterna, and extreme distress of respiratory [29].

3.2. Volatile Organic Contamination Migrated from Polyvinylchloride (PVC)

As shown in Table 5, the concentration of targeted VOC migrating from PVC polymeric pipes had a considerable rising tendency among the increase of retention time, suggesting that under long incubation conditions, organic contaminants migration from PVC polymeric pipes would build up fast and tend to deteriorate the quality of water [30,31].

All VOCs contaminants occurring in drinking water samples have been identified in the water leach ability test [32,33]. CTC concentration increases after 5.19 µg/L to 12.64 µg/L at 48 h of incubation [34–36]. There was a slight increase of CTC concentration in the deionized water samples after 48 h and 72 h of incubation. Table 6 shows the amount of other leached targeted contaminants from three incubation times ranging from 24.72 ± 1.44 µg/L (chloroform), 5.58 ± 0.29 µg/L (toluene), 0.061 ± 0.03 µg/L (styrene), 0.49 ± 0.09 µg/L (bromoform), 0.57 ± 0.07 µg/L (DBM), 1.98 ± 0.13 µg/L (Cis-1,3-DCP), 2.20 ± 0.13 µg/L (trans-1,3-DCP), and 0.98 ± 0.07 µg/L (o-xylene). The order of the components (higher to lower) were chloroform > CTC > toluene > Trans-1,3-DCP > Cis-1,3-DCP > DBM > bromoform > styrene.

The results indicated that concentrations of volatile organic compounds were released from polymeric plastic pipes [37,38]. The leakage of antioxidant degradation product from polymeric pipes have also been documented [39]. The values of Pearson correlation matrix in Tables 7 and 8 reveal strong correlations between the concentrations of most of the analyzed contaminants. This trend confirms that leaching components migrate from the same source [40]. Markedly, the concentration of leachable volatile compounds increases with extended stagnant time [41,42]. Even though the levels of some of the organic components identified in this migration experiments are below the permissible limit of MCL, their prolonged exposure can pose danger to human health [35,43].

Table 7. Correlation matrix Pearson (n) for VOCs in drinking water samples.

Variables	CTC	Chloroform	Toluene	Styrene	Bromoform	DBM	Cis DCP	TraDCP	Xylene
CTC	1								
Chloroform	0.489	1							
Toluene	0.548	0.304	1						
Styrene	-0.067	0.133	0.314	1					
Bromoform	0.220	-0.082	-0.066	-0.176	1				
DBM	0.526	0.147	0.044	-0.014	0.163	1			
Cis-DCP	0.251	0.304	0.594	0.289	-0.167	0.098	1		
Tran-DCP	0.370	0.584	0.432	0.297	-0.159	0.165	0.710	1	
O-xylene	-0.084	-0.035	-0.033	0.699	0.417	-0.034	-0.060	-0.045	1

Table 8. Correlation matrix Pearson (n) for VOCs leached from plastic pipes.

Variables	CTC	Chloroform	Toluene	Styrene	Bromoform	DBM	Cis DCP	TraDCP	Xylene
CTC	1								
Chloroform	0.941	1							
Toluene	0.512	0.773	1						
Styrene	0.111	0.442	0.911	1					
Bromoform	-0.824	-0.967	-0.908	-0.655	1				
DBM	-0.399	-0.686	-0.992	-0.956	0.848	1			
Cis-DCP	0.585	0.276	-0.397	-0.741	-0.023	0.510	1		
Tran-DCP	-0.372	-0.665	-0.988	-0.964	0.833	1.000	0.535	1	
O-xylene	-0.541	-0.794	-0.999	-0.896	0.922	0.987	0.366	0.982	1

4. Conclusions

It was found that three different types of PVC pipes examined in this study contribute to significant levels of VOCs contamination compared to other types of plastic pipes that are available in the market. In practice, shorter duration of incubation period is more common for premise with plumbing pipes in inhabited homes compared to the incubation periods of three days (72 h). However, longer duration of incubation periods is more common for newly constructed and not yet-inhabited buildings where the construction is still in progress. Use of different types of PVC pipes produces different levels of VOCs contaminants in drinking water. The present study provides apparent signal pertaining to water contamination due to discharge from polymeric piping and plumbing substances in residential and domestic water distribution systems. It is recommended that materials, chemicals, and processes connected to the home water distribution network are rigorously evaluated before use to determine the potential to cause significant levels of VOCs contamination. In addition, extending the curing period substantially reduced the degree of leaching of these organic contaminants from the PVC pipes into water. However, further work is necessary to investigate different contact periods and elucidate the role of disinfectants in altering leached organic compounds.

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